Space Weather Technical Forecast

Issued on Thursday, 30 November 2023 at 13:28 Local

This technical forecast provides a four day assessment of space weather events. The probabilities stated below are for reaching or exceeding the given levels. For more information about space weather impacts please see the Met Office Space Weather Scales https://www.metoffice.gov.uk/weather/learn-about/space-weather/uk-scales

Space Weather Forecast Headline: M-flares likely (R1-R2 Blackouts). G1-G2 Minor to Moderate storms likely, with a slight chance G3 Strong storms, from multiple CME arrivals day 1-2 (30 Nov-01 Dec)

Analysis of Space Weather Activity over past 24 hours

Solar Activity: Low, with peak flare C3.8 at 29/1435 UTC, from AR3500, located in the southwest of the disc. There are currently twelve sunspot regions with AR3500 the largest and most active. The region is currently comprised of a cluster of small umbrae with a relatively simple magnetic structure. Some spreading of the spots was observed, but also the development of further small umbrae within the intermediate portion of the group. All other regions on the disc remain smaller and simpler, and generally either stable or showing signs of decay. There are also a number of filaments on the Earth-facing disc.

No Earth-directed CMEs occurred during this period, however there are a number of other potentially Earthbound CMEs in the forecast from previous days.

Solar Wind / Geomagnetic Activity: Solar wind speeds, as observed by ACE and DSCOVR at L1, were Slightly Elevated to near Background, 380-420 km/s initially, but decreased to around 350km/s by the end of the period. Density was generally below average. Interplanetary Magnetic Field (IMF), Bt, was weak throughout, varying between 3-6 nT, with the north-south component, Bz, also varying weakly but predominately negative (southward orientated). Phi angle was mainly positive (away from the Sun). Geomagnetic activity was Quiet (Kp1-2).

Energetic Particles / Solar Radiation: GOES16 high energy (greater than 10MeV) proton flux remained at background. GOES16 high energy (greater than 2MeV) electron flux varied between Background and moderate, peaking at 393 pfu at 29/1545 UTC. The associated 24-hour fluence has remained below the Active threshold (1e8 integrated pfu). The observation at 30/0000 UTC was 1.11e7 integrated pfu.

Four-Day Space Weather Forecast Summary

Solar Activity: Low to Moderate with isolated M-flares (R1-R2 Blackout) likely, and a slight chance of an isolated X-class flare (R3 Blackout). AR3500 is most likely to be the source of any significant flares.

Solar Wind / Geomagnetic Activity: There are up to four Earth-directed CMEs. Three originate from filament eruptions on 27 Nov, and the other, a more significant CME, originated from the M9.8 flare of AR3500 on 28 Nov. Two of the filament eruption CMEs are likely to arrive day 1 (30 Nov), with glancing impacts most likely, but could combine into a more notable enhancement. The M9.8 sourced CME is forecast to arrive on day 2 at 01/1000 UTC, although the speed of this CME is low confidence, allowing for a chance of an arrival as early as late on day 1 (30 Nov). This CME is also likely to sweep up and cannibalise the fourth CME, which was forecast to arrive later on day 2 (01 Dec), potentially enhancing the impact when this occurs. Aside from the CMEs, current Slightly Elevated to Background winds are forecast to continue easing. Geomagnetic activity is initially expected to be mainly Quiet. The CME arrivals are then likely to bring spells of G1/Minor or G2/Moderate geomagnetic storms on day 1 or more likely day 2 (30

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Nov or 01 Dec) with a slight chance of G3/Strong storms. Geomagnetic activity then easing day 3 (02 Dec) although there remains a chance of isolated G1 Minor Storms, before returning to mainly Quiet by day 4 (03 Dec).

Energetic Particles / Solar Radiation: GOES16 high energy proton flux is expected to remain at background levels. However, any significant flares, mainly from AR3500, or any notable filament eruptions will bring a chance of flux levels increasing, with a slight chance of approaching or perhaps exceeding the S1 Minor Radiation Storm level. Electron flux is forecast to be Background to Moderate at first, but likely falling to persistently Background with any CME arrival. Some recovery of flux to Moderate, perhaps High at diurnal peak, is likely days 3-4 (02-03 Dec). The associated 24 hour fluence is forecast to remain below Active (1e8 integrated pfu).

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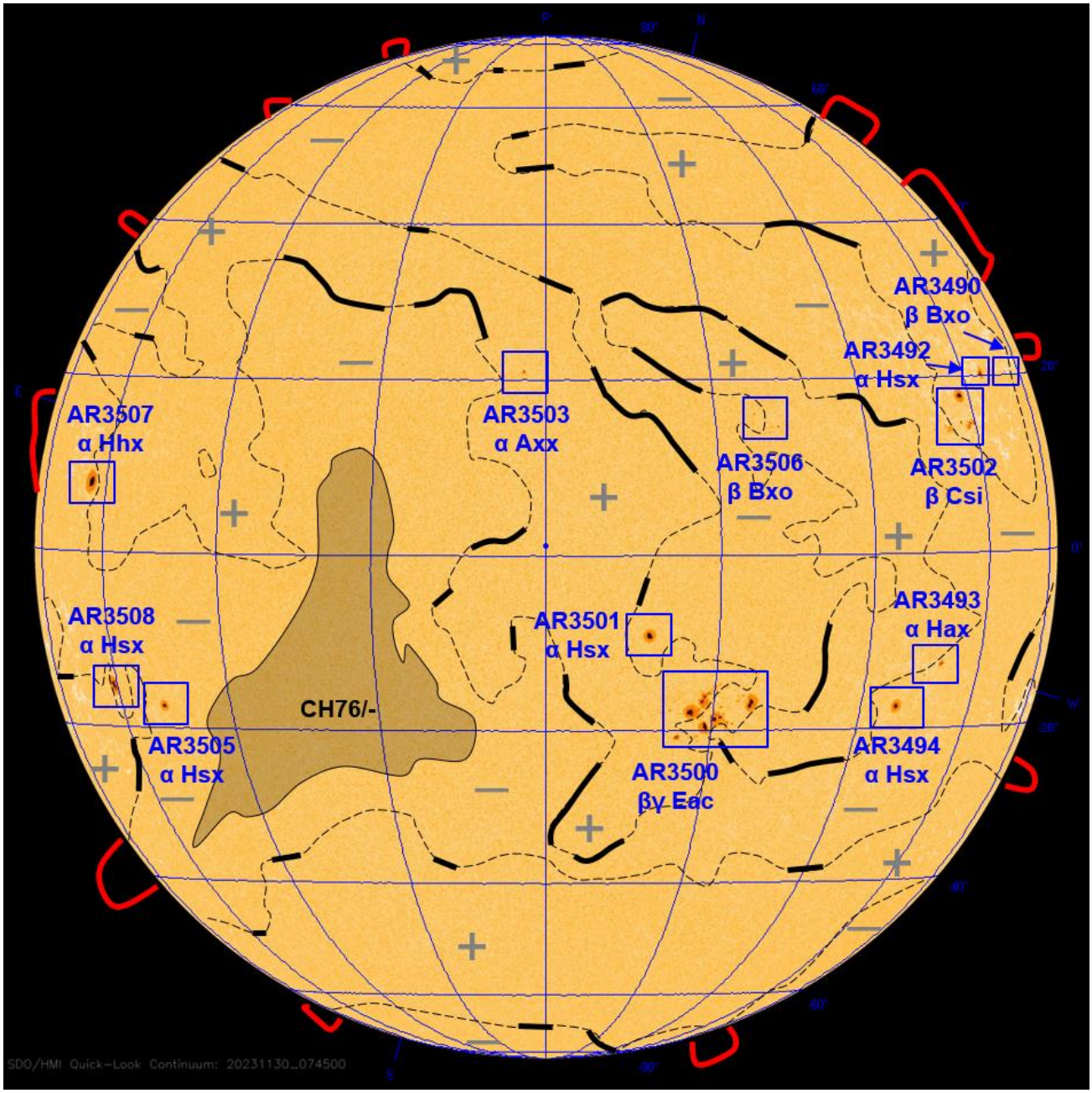
Figure 1. Solar Analysis Valid 30/0745 UTC.



Key: Filament ___ , Prominence ___ , Magnetic Field Line - - - , Polarity +/-, Coronal Holes: Grey shaded area CHxx +/-, Sunspot groups 25xx - Mt Wilson α-β-βγ-βγδ and Zurich-McIntosh Axx etc.

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Geomagnetic Storms:

There are up to four Earth-directed CMEs.

Two glancing impacts are possible on day 1 (30 Nov). The first was due to a filament eruption from the southwest disc around 27/0535 UTC off the southwest disc and was forecast to give a glancing impact at around 30/0700 UTC, although the bulk of the material passing beneath Earth. A minor discontinuity in solar wind data around 30/0000 UTC may be from this event. The second is due to a large filament eruption off the northeast disc 27/2340 UTC. This is a faster CME, that is expected to largely miss behind and north of Earth, however there is a potential for a glancing impact around 30/2300 UTC, although a faster arrival is possible, potentially combining with the first arrival. It is also possible that both of these could miss.

Two CME arrivals are also likely on day 2 (01 Dec). The most significant is the halo CME from the M9.8 flare at 28/1950 UTC from AR3500. This CME is very likely to be Earth directed with current expected arrival of 01/1000 UTC, however the CME speed is low confidence with the possibility for both faster solutions, potentially arriving late day 1 (30 Nov), or a later arrival on day 2. The final CME is due to a filament eruption from the northeast disc around 27/1840 UTC, coincident with a C6.7 flare from AR3500 in the southeast. This produced a faint and slow partial halo CME that was observed heading southeast, and was expected to arrive around 01/1800 UTC. However this CME is now likely to be swept up and potentially cannibalised by the above CME, perhaps enhancing the potential impact from it.

Aside from the CMEs, solar winds are expected to be at Background with no coronal hole sourced enhancements forecast.

Geomagnetic activity is initially expected to be Quiet with a chance of isolated Unsettled spells. The various CME arrivals are then likely to bring G1/Minor or G2/Moderate geomagnetic storms on day 1 or 2 (30 Nov or 01 Dec) with a slight chance of G3/Strong storms. These most likely on day 2 (01 Dec) with the M9.8 flare CME arrival. Geomagnetic activity then easing day 3 (02 Dec) although there remains a chance of isolated G1 Minor Storms, before returning to mainly Quiet by day 4 (03 Dec).

Geo-Magnetic Storm Probability (Exceedance)	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Minor or Moderate	G1 to G2	No	40	70	20	1
Strong	G3	No	10	25	1	1
Severe	G4	No	2	5	1	1
Extreme	G5	No	1	1	1	1

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Geomagnetic Activity - Earthbound Coronal Mass Ejections

Date/time 21.5R (UTC)	Halo: Full or Partial	Source	Source Location	Estimated Speed	Estimated Arrival Time	Comments
27/1235	Nil	Filament Eruption	SW	575 km/s	30/0800 UTC	Glancing impact
28/0302	Partial	Filament	NE	1040 km/s	30/2300 UTC	Likely miss, low chance glancing impact
28/0700	Partial	Filament and C6.7 flare	NE	380 km/s	01/1800 UTC	Likely to be swept up by CME below
29/0056	Full	M9.8 flare (AR3500)	S-centre disc	740 km/s	01/1000 UTC	Low confidence on speed: -12/+6 hr arrival time range

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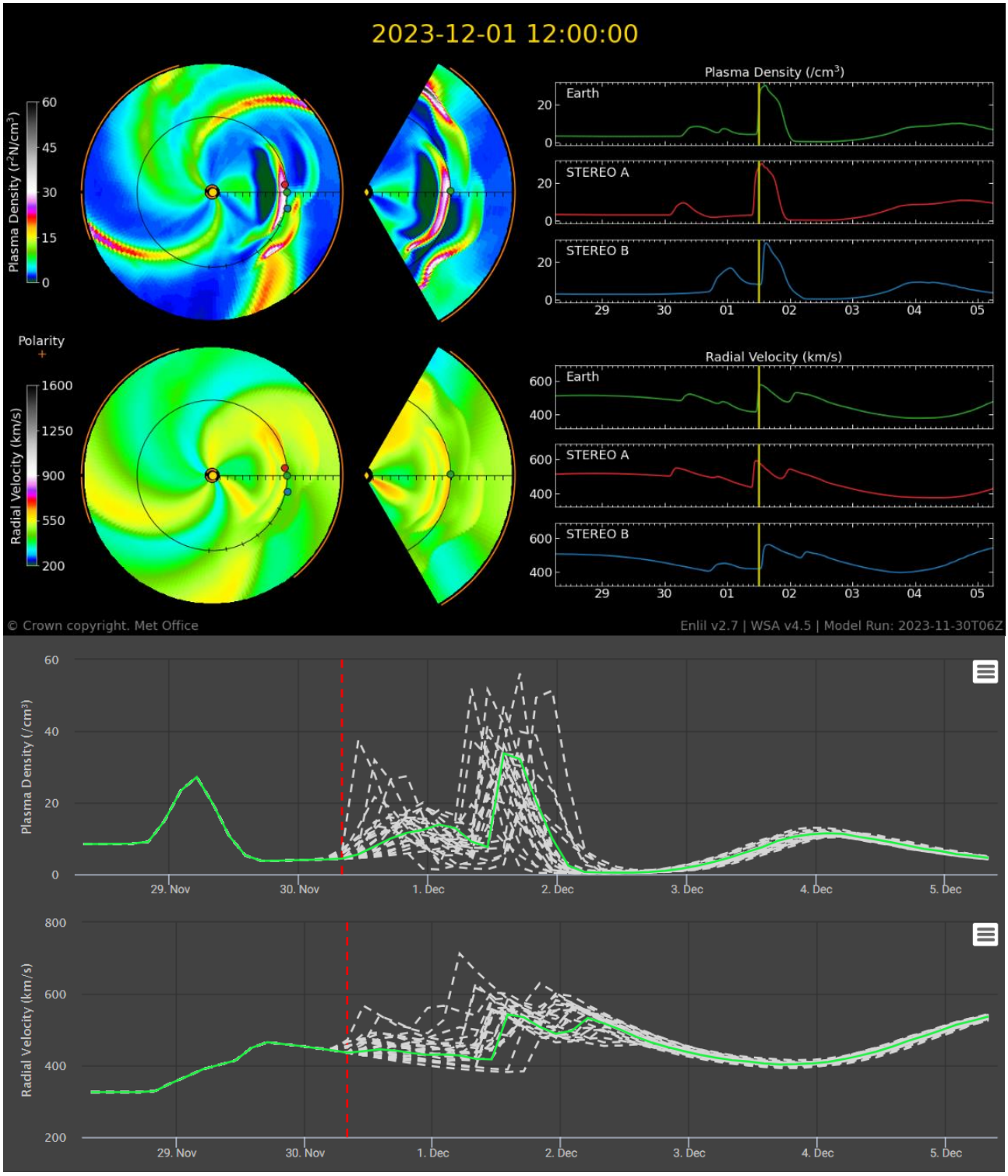
Figure 2: Latest MOSWOC Enlil forecast showing estimated arrival time of full-halo CME (with ensemble)


2023-12-01 12:00:00
Plasma Density (/cm³)
Earth
STEREO A
STEREO B
Plasma Density (r²N/cm³)
Polarity
Radial Velocity (km/s)
29 30 01 02 03 04 05
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Enlil v2.7 | WSA v4.5 | Model Run: 2023-11-30T06Z
Plasma Density (/cm³)
Radial Velocity (km/s)
29. Nov 30. Nov 1. Dec 2. Dec 3. Dec 4. Dec 5. Dec

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Radio Blackouts - X-Ray Flares:

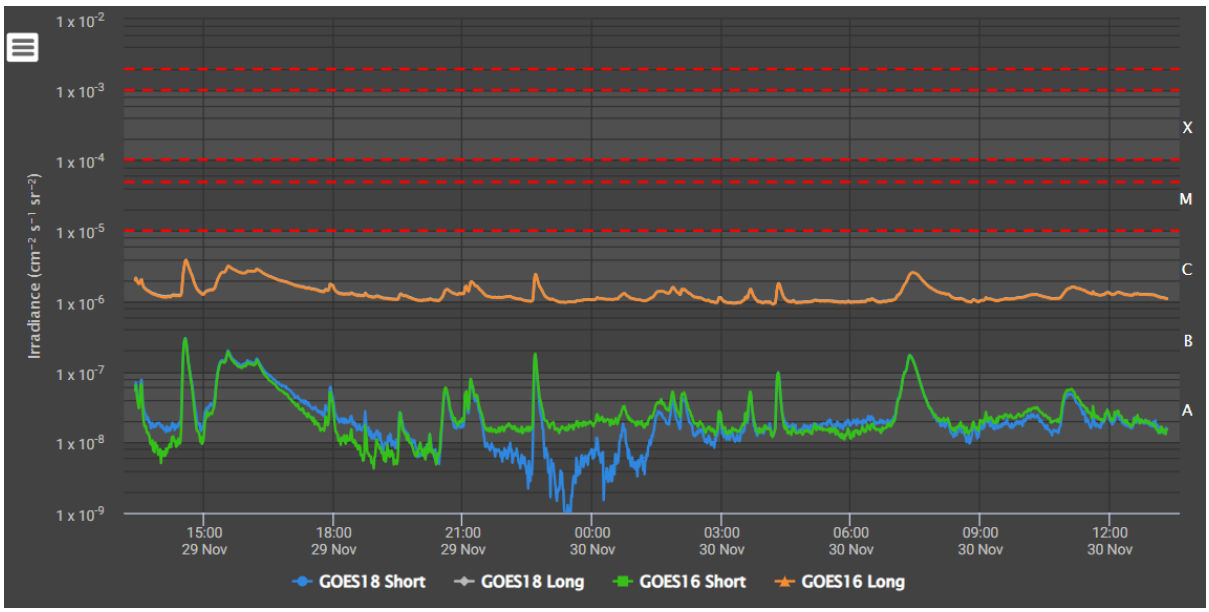
Low to Moderate activity is forecast, with a likelihood of isolated M-flares.

There are twelve sunspots on the disc. AR3500, the source of the M9.8 flare on 27 Nov, continues to be the largest and most significant region. This is composed of a moderately sized cluster of small spots but with a fairly simple magnetic parity separation line and subsequently of a relatively simple magnetic configuration. Furthermore the leader spot has been spreading from the main cluster, leading to a spreading of the group. However, there has been some ongoing development, with the growth of small spots within the intermediate part of the region, and while no delta spot is currently present there remains strong opposite polarity umbrae close to the magnetic inversion line. This suggests that while flares are likely to be isolated, when they do occur there is the potential for high M-flares (R2 Blackouts) with a slight chance of X-flares (R3 Blackouts).

Otherwise, despite the number of spots across the rest of the disc, they remain relatively small and simple, with a number of mature and stable unipolar "H" spots.

X Ray Flares	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC)	Day 2 (00-24 UTC)	Day 3 (00-24 UTC)	Day 4 (00-24 UTC)
Probability			(%)	(%)	(%)	(%)
Active	R1-R2 M Class	No	60	55	45	45
Very Active	R3 to R5 X Class	No	10	10	10	10

Figure 3: GOES 16/18 X-ray flux



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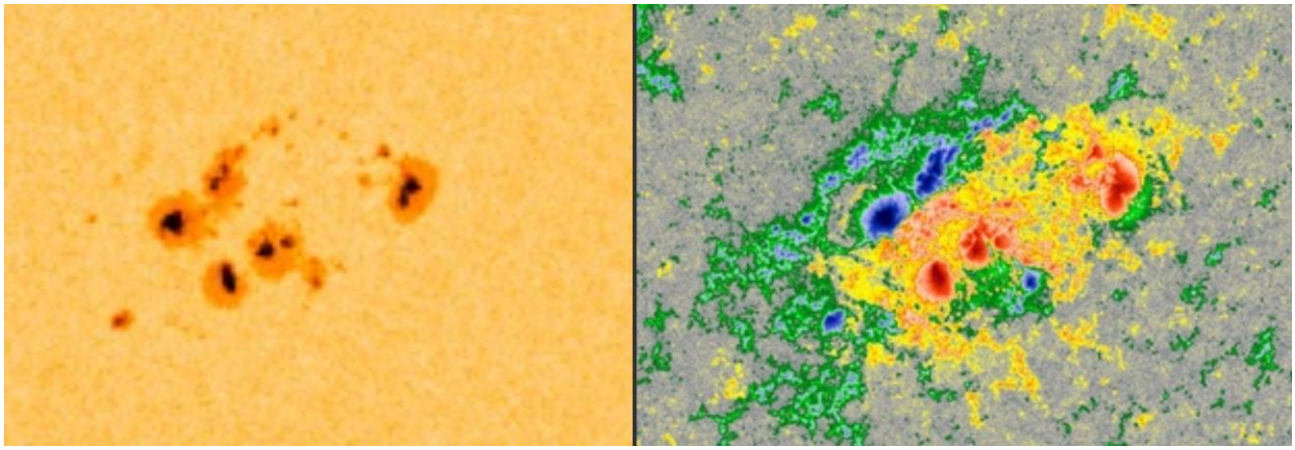
Solar Radiation Storms - (High Energy Protons):

The high energy (greater than 10MeV) proton flux observed by GOES16 is currently at background and expected to remain at this level. However, with the number of spots and filaments on the disc, there is a chance of flux increasing in response to any significant flares or eruptions. The main risk is from AR3500, in the southwest disc. This was the source of an M9.8 flare late on 28 Nov, and while no proton response was observed at Earth on this occasion, any subsequent flares will also have the potential to increase the observed proton flux.

Radiation Storms Probability (Exceedance)	Level (cm^{-2} sr^{-1} s^{-1})	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	≥ S1	No	10	10	10	10
Very Active	≥ S3 *	No	1	1	1	1
* S3 ≥ 10 MeV ≥ 1000 pfu and / or ≥ 50 MeV ≥ 10 pfu. (pfu = $cm^{-2}sr^{-1}s^{-1}$)						

Figure 4: SDO intensitygram and Magnetogram (color) of AR3500 at 30/1200 UTC



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High Energy Electrons Event (≥ 2MeV):

High energy electron flux (greater than 2MeV) as observed by GOES-16 is currently varying between Background and Moderate, however the arrival of multiple CMEs day 1 and day 2 (30 Nov and 01 Dec) is likely to drop these values to persistently background. There is some potential that as solar wind pressure day 3 and day 4 (02-03 Dec) flux will recover to give more persistently Moderate values, and a slight chance of High flux at diurnal maximum.

The associated 24 hour electron fluence is expected to remain below the Active threshold (1e8 integrated pfu), as supported by REFM. However, a rising trend is likely from day 3 onward, once any CME influence recedes.

GEO Electron Environment Probability (Exceedance)	Level (cm^{-2} sr^{-1} day^{-1})	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	**≥ 2 MeV ≥ $1x10^8$**	No	1	1	1	10
Very Active	**≥ 2 MeV ≥ $1x10^9$**	No	1	1	1	1

Figure 5: GOES-16 >2MeV Electron Flux and Fluence with REFM and Recurrence

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